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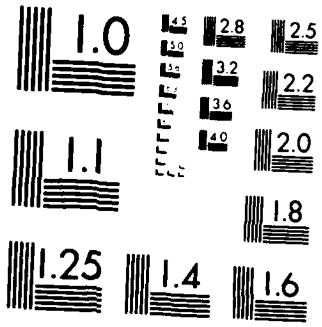

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Progress on three research problems in Command and Control Theory is described.

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PROGRESS REPORT

for the period

1 September 1987 to 31 December 1987

for

COMMAND AND CONTROL THEORY

Contract Number N00014-85-K-0782

Work Unit NR 564-001

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800 N. Qunicy Street
Arlington, VA 22217-5000

cc: CDR. M. Giehl

Submitted by:

Alexander H. Levis
Michael Athans

January 15, 1988

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1939-1959
ELECTRONIC SYSTEMS LABORATORY
1959-1978

COMMAND AND CONTROL THEORY

1. PROJECT OBJECTIVES

The main goal of this research is to start bridging the gap between mathematical theories of command and control and empirical studies. More specifically, the goal is to develop theories on the one hand and to model experimental paradigms on the other, so that realistic problems in command and control (C^2_U) can be studied prior to the design of experiments and the collection of relevant data.

The research program undertaken for this project has three main objectives:

(a) The extension of a mathematical theory of C^2_U organizations so that it can be used to design an experimental program;

(b) The further development of an analytical methodology for measures of effectiveness, and

(c) The investigation of organizational architectures for distributed battle management (many weapons on many targets resource allocation problems).

The unifying theme of this research is the concept of distributed information processing and decisionmaking. The emphasis is on the development of models and basic analytical tools that would lead to the design of an experimental program as contrasted to ad hoc experimentation.

The project draws upon and contributes to the theoretical developments on naval distributed tactical decisionmaking (DTDM) being pursued in parallel under ONR Contract No. N00014-84-K-0519. The co-existense of the two programs has made it possible to undertake long-range, basic research on fundamental issues and problems in command and control.

2. STATEMENT OF WORK

The research program has been organized into five tasks, four that address the research objectives and a fifth that addresses the question of disseminating the results of this project both directly to the members of the Basic Research Group of the Technical Panel on C^3 of the Joint Directors of Laboratories and to the C^3 community at large through publications and presentations.

2.1 RESEARCH TASKS

TASK 1: Development of Computer-Aided Design System

1.1 Develop the specifications for the Computer-Aided Design System. Specifically, design the data base, the architecture generator, the performance-workload locus module, and the analysis and evaluation module. The system should be able to handle a generic five member, three echelon organization.

1.2 Implement the design developed in Task 1.1. Design the graphics module to be used in presenting the performance-workload locus and its projections as well as the loci obtained from the analysis and evaluation module.

1.3 Design and implement the user interface. Use the Petri Net formalism for the specification of the interactions between organization members and the design of protocols.

TASK 2: Command and Control Organization Design and Evaluation

2.1 Develop and implement a set of tasks, as well as sets of information processing (situation assessment) and decision-making (response selection) algorithms for use with the decisionmaker models. These tasks and algorithms should be appropriate to future experimental efforts.

2.2 Use organizations with up to five members to exercise and test the CAD system developed in Task 1.

2.3 Analyze and evaluate command and control organizational architectures using the CAD system. Begin developing hypotheses that can be tested through experimental efforts.

2.4 Incorporate in the design system and in the analysis module the theoretical results obtained from parallel research projects.

TASK 3: <u>C^3 Organizations and Architectures for Distributed Battle Management</u>

3.1 Develop a unified theory for complex engagements of several weapons against several targets. Assume imperfect defensive weapons systems so that the elemental "one-on-one" kill probability is non-unity. Also assume imperfect defensive surveillance so that the target/decoy discrimination probability is non-unity.

3.2 Develop several "many-on-many" engagement strategies and evaluate their impact upon decentralized C^3 system requirements and architectures. Develop the necessary tools so as to design distributed C^3 architectures compatible with the engagement strategies.

3.3 Illustrate the tactical doctrine and C^3 interface requirements via computer simulations. Develop hypotheses that could be tested in the field.

TASK 4: Measures of Effectiveness

4.1 Conceptual Development. Develop and refine the concepts and definitions of measures of effectiveness (MOEs), measures of performance (MOPs), and system/mission parameters. Interpret the concept of measure of force effectiveness (MOFE) as a global effectiveness measure in the context of C^3 systems.

4.2 Implementation of the Methodology. Develop a quantitative framework where models of various types can be used to estimate measures of performance (MOPs). Develop analytical, computational and graphical tools for measuring effectiveness (MOEs). Begin the implementation of these techniques on the same workstation used for Task 1 with the objective of developing a system based on MOE evaluation that can be used as an aid in system development and selection. Note that many of the software utilities to be developed are common to Tasks 1 and 4.

4.3 Implication of the Methodology. Illustrate the various conceptual and technical developments with examples drawn from actual or planned C^3 systems. Apply the methodology to an evolving C^3 system. While motivated by real systems, the applications will be described in generic terms.

TASK 5: Information Dissemination

5.1 Participate in technical sessions of the Basic Research Group to be held approximately once per calendar quarter.

5.2 Present the research results at technical conferences and meetings and publish articles in archival journals.

3. PROGRESS REPORT

During this four-month period (September to December 1987) the research effort focused on the completion of the first version of the computational and graphical tools to be used in the design of organizations, i.e., the development of CAESAR (Computer-Aided Evaluation of System Architectures), on the analysis of the first experiment involving human subjects, and on the completion of two theses.

3.1 Development of Computer-Aided Design System

The computer-aided design system, which was named CAESAR for Computer-Aided Evaluation of System Architectures, consists of four major components:

The Architecture Generator which constructs feasible organizational forms using the Petri Net formalism.

The Analysis and Evaluation Module which contains algorithms for the analysis of organizational architectures and the computation of Measures of Performance (MOPs).

The Data Base which is used to store the results of the analysis (the MOPs) of organizational architectures.

The Locus module which contains routines that construct the Performance-Workload locus of an organizational form that is carrying out a given task, as well as routines that compute and present graphically selected measures of effectiveness (MOEs).

The structure of the software system is shown in Figure 1. CAESAR incorporates theoretical and computational developments obtained over a period of seven years through more than ten completed theses and six more in progress. Some modules are being developed explicitly under this contract; others are being developed with support by the Distributed Tactical Decision Making initiative of the Office of Naval Research.

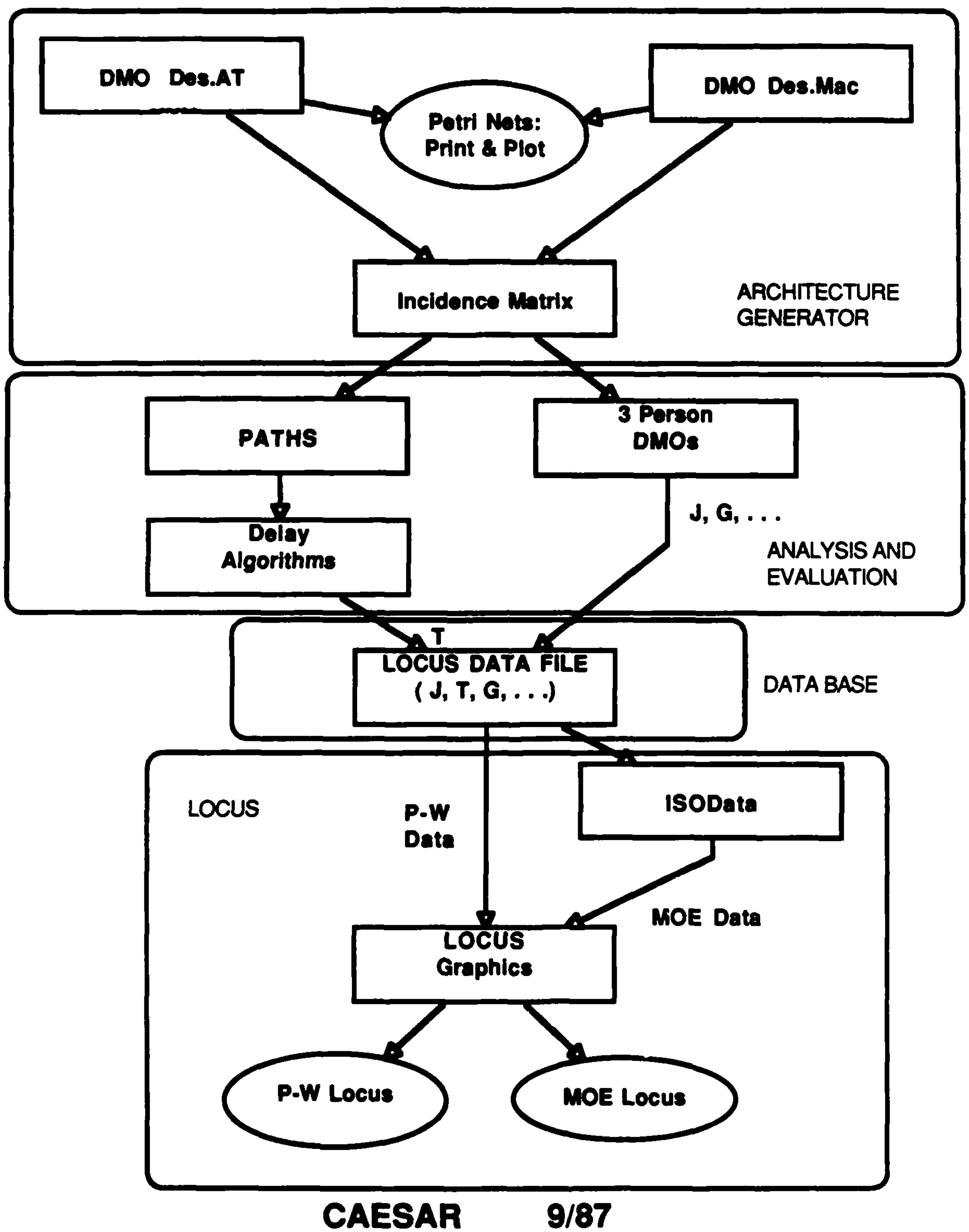


Figure 1. Computer-Aided Evaluation of System Architectures

A simplified portable version of CAESAR, shown in Figure 2, was demonstrated on September 29, 1987 at the annual review meeting of the DTDM program held at the Naval War College, Newport, Rhode Island.

During this reporting period, the module DMO Des.AT was completed and documented. The purpose of this task was to develop a Petri Net Computer Aided Design (PN/CAD) Software System for creating organizational architectures of arbitrary complexity. The system developed by I. Kyratzoglou under the supervision of Dr. A. H. Levis, provides tools for analysis and manipulation of organizational attributes and a standard input/output interface.

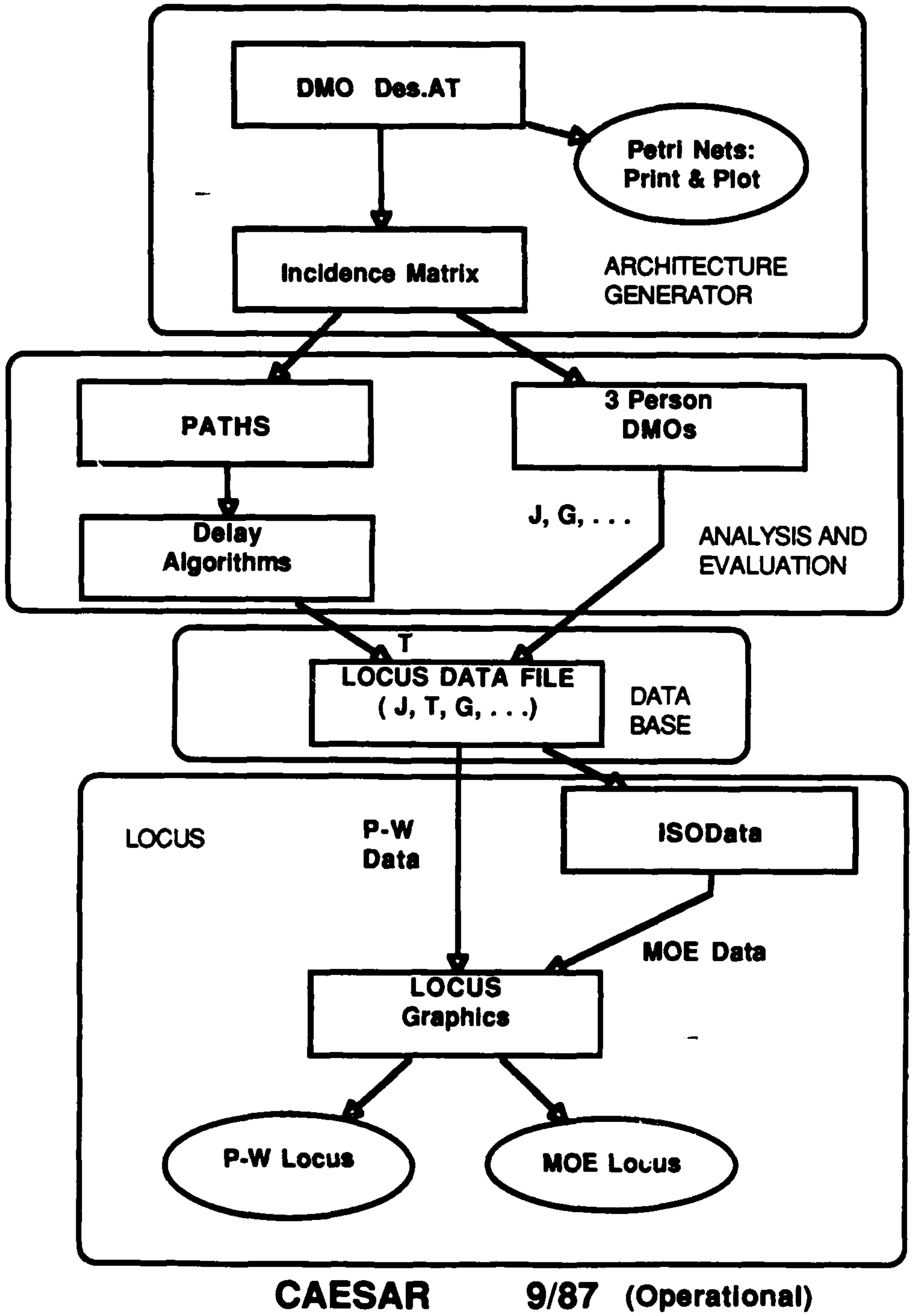
This PN/CAD System is used for constructing and analyzing arbitrary organizational architectures. It can create or decompose supernodes, implement switches, combine generic architectures to form a large organizational structure, store information represented by places, transitions, switches or connectors, and produce specific structural properties of the Petri Net. The PN/CAD System is composed of four Functions, as shown in Figure 3:

- o A Graphics Editor, used for the interactive generation of the Petri Net structure of the organization.

- o A Text Editor, used to store, modify and retrieve attributes assigned to places, transitions, switches and connectors.

- o An Analysis Function, used to generate the interconnection matrix, the incidence matrix and the information flow paths of an organization.

- o A Hardcopy Function, used to produce a hardcopy of the graphic image of the organizational architecture and its information flow paths.


DMO Des.AT
Petri Nets:
Print & Plot
Incidence Matrix
ARCHITECTURE
GENERATOR
PATHS
3 Person
DMOs
Delay
Algorithms
J, G, . . .
ANALYSIS AND
EVALUATION
T
LOCUS DATA FILE
(J, T, G, . . .)
DATA
BASE
LOCUS
P-W
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MOE Data
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Graphics
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CAESAR 9/87 (Operational)

Figure 2

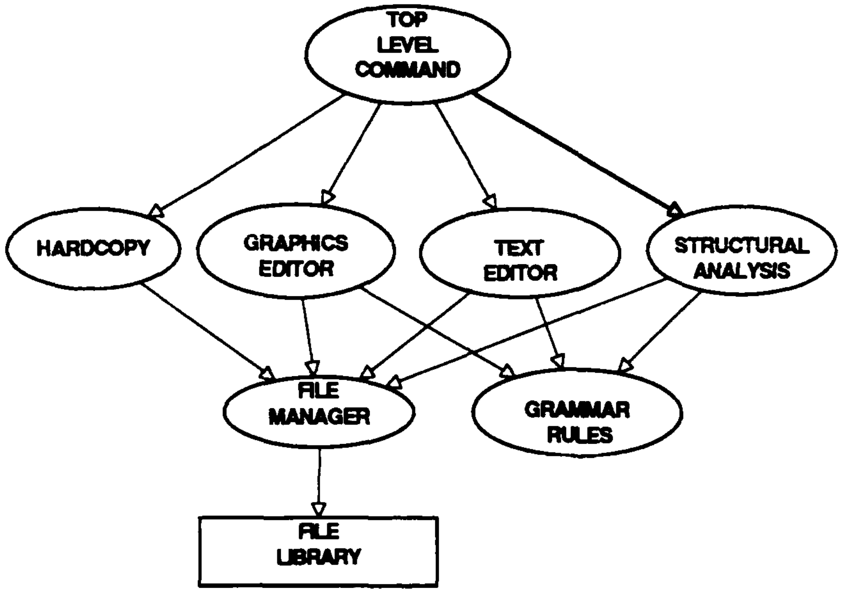

Figure 3. The PN/CAD System Chart

In addition, at Top Command Level, a graphics command interpreter evaluates the commands and activates the request mode of operation. A File System provides a large set of auxiliary services such as File Request, File Manipulation and File Management. Grammar-Rule algorithms check for the proper graphical construction of the organization, and enforce the constraints during analysis of organizational architectures.

The PN/CAD Software drives a wide variety of output devices such as: various printers, two and six pen plotters, the Professional Graphics Display monitor, when it operates with the Professional Graphics Controller, and various monitors when it operates with the Enhanced Graphics Adapter.

The interactive organizational design process involves three phases. The first phase involves the conceptual and graphic design stages. A set of Petri Net generic structures is identified from the organizational model and constructed graphically by invoking the Graphics Editor. These structures are used as building blocks for composing the overall architecture. For example, in the case of developing a Distributed Decision-Making Organization (DDMO) archiecture, two, three, or four stage Petri Net models, representing designer's or system contraints, may be constructed and used. Structural decomposiion is used to resolve an existing architecture into constituent components. Then, the notion of graphical abstraction is introduced for representing a subnet as a single entity. A subnet may be defined as a supernode. In such a case, supernodes replace subnets in the graphical structure, thus creating a coarsened version of the organizational model. The PN/CAD Software System has its own metafile system to store the graphics structure of the organization.

The second phase involves the construction of an alphanumeric data structure by invoking the Text Editor. The data structure contains attributes which correspond to representations of places, transitions, switches and connectors in the graphic image. Attributes may include processing algorithms and delays for transitions, token capacity for places, functional relations and probabilities for connectors, file names for subnets, etc.

The third phase involves the creation of an analytical description of the organizational model. Data processing algorithms access the metafile, process its contents, and generate the incidence matrix. The incidence matrix serves as input to an algorithm which produces a matrix containing the minimal supports of S-invariants. The matrix is used to create the information flow paths.

The PN/CAD Version 1.0 Software System is being used now for the graphical and analytical description of organizational architectures. The system has been tested and it has been found to have features that make it capable of being adapted easily to the designer's needs. The internal structure of the PN/CAD System is modular. The systems programmer may improve already existing algorithms or test new ones easily. New Functional Modules may be defined and added.

The Graphics Editor capabilities are essential for the growth and flexibility of the design. The Text Editor provides easy attribute access. The attributes can be used from Graphics Editor commands to generate the family tree of an organizational architecture by implementing different switch settings. The Analysis Function provides a set of descriptive analytical tools. The Hardcopy Function produces standard output on a plotter or printer. Novice users may access the HELP facility.

Documentation: The thesis has been completed and the report distributed.

[1] J. Kyratzoglou, "Computer Aided Design for Petri Nets," LIDS-TH-1694, Laboratory for Information and Decision Systems, MIT, Cambridge, August 1987.

3.2 Organizational Designs

3.2.1 Modeling and Evaluation of Expert Systems in Decisionmaking Organizations

This research task was initiated in February 1987 by Didier M. Perdu under the supervision of Dr. A. H. Levis. In previous work (Chyen, 1984), the effect of computational decision aids (such as preprocessors of incoming data) on an organization's performance was investigated. However, the intensive efforts to develop and implement decision aids that perform symbolic manipulations and incorporate expert systems have raised the question of how they will affect decisionmaking in C^3 organizations.

In this project, a model of an expert system with fuzzy logic as a means for dealing with uncertainty has been developed using the Predicate Transition Nets formalism. This has been done through the modeling of the basic logic operators AND, OR, and NOT. The combination of these operators makes it possible to represent the inference net of a consultant expert system using production rules and to study its behavior dynamically. A method to make time-related measures from this representation has been introduced, taking into account the portion of the rule base scanned by the system and the number of interactions with the user.

This model of an expert system has been applied to an example of a two decisionmaker organization facing the problem of fusion of inconsistent information. The decisionmaker must identify the trajectories of missiles that they then have to destroy to protect a set of facilities. In this application, the expert system helps the decisionmaker to clarify the contradictory situation assessment he has to fuse: (1) ignoring the assessment of the other decisionmaker, (2) making a weighted choice among the two contradictory situation assessments, by taking into consideration the way the data used to produce these assessments have been obtained by each decisionmaker. Measures of performance (workload, timeliness and accuracy) have been evaluated. The results show that the use of the expert system improves significantly the accuracy of the organization, but requires more time and increases the workload of the decisionmaker using it. The comparison of the two models of interaction between the user and the system has shown variations in workload and in response time: the computer initiated mode requires less workload and less response time for a same level of accuracy. This result tends to show that the design of an interacting decision aid must take into account not only the characteristics of the problem to be solved, but also the way the decisionmaker would use it.

The formulation of a general methodology for designing decision aids could be an interesting extension of the study of command and control organizations. In the application studied in this task, the measures of performance of the organization have shown to be very sensitive to the mode of interaction, the kind of decision aid used (boolean logic system vs. fuzzy logic systems) and the definiion of the mapping functions deducing the degree of truth of the evidence handled by the expert system from the data entered by the user. Therefore, the methodology used to study decisionmaking organizations can be extended for the design of interacting decision aids. For a given set of inputs, design alternatives could be compared and validated to select the one which gives the best measures of performance.

<u>Documentation:</u> The thesis has been compl eted and the report is being printed for distribution.

[1] D. Perdu, "Modeling and Evaluation of Expert Systems in Decision-Making Organizations," LIDS-TH-1726, Laboratory for Information and Decision Systems, MIT, Cambridge, MA, December 1987.

3.2.2 Structural Properties of Organizational Archiectures

Joseph S. Oliveira under the supervision of Dr. A. H. Levis is examining the discrete structural aspects of organizational architectures with the primary goal being the identification of an architecture's combinatorial invariants. The mathematical conjecture is that the order structure of an organizational architectures, as determined by its operational constraints, allows that architecture to be enumeratively classified as a Matroid. The combinatorial invariants of a Matroid can be equated with a greedoid. Greedoid invariants explicitly determine optimization algorithms. These algorithms are then employed to design and reorganize decisionmaking organizations.

Documentation: A preliminary technical memo on the feasibility of the approach will be prepared in late January 1988.

3.3 C^3 Organizations and Architectures for Distributed Battle Management

Project Objective: The long-range goal of this research is to understand basic issues associated with Battle Management/C3(BM/C3) architectures for the case of many weapons engaging several targets. The defensive weapons are assumed imperfect, and the targets may have a finite probability of being decoys. Thus, the problem is one of wise Weapon-to-Target (WTA) assignment strategies, and their interface with other BM/C3 functions. We also seek the evaluation of centralized, decentralized, and distributed BM/C3 architectures that support such "many-on-many" engagements.

Problem Definition: Several formulations of the problem are possible. Suppose that we have a total of M weapons which we are willing to commit against a total of N targets. At the most general level, the effectiveness of each weapon can be different against each target; this can be quantified by having a different kill probability p_{ij} for weapon j assigned against target i (j=1,2,...,M; i=1,2,...,N). The WTA function should allocate the right weapons against the correct targets so as to minimize some cost function.

The simplest cost function is leakage, i.e., the expected number of surving targets. Thus, if we adopt an optimization framework, we wish to minimize the leakage L which is given by

$$L = \sum_{i=1}^{N} \prod_{j=1}^{M} (1-p_{ij}x_{ij}) \tag{1}$$

by selecting optimally the M.N allocation decision variables x_{ij}, each of which is either 0 or 1. Thus, $x_{ij} = 1$ if the j-th weapon is assigned to the i-th target and 0 otherwise and

$$\sum_{i=1}^{N} x_{ij} = 1 \quad , \quad j = 1,2,\ldots,M \tag{2}$$

which simply states that each weapon can only engage a single target.

The solution of such optimization problems for the WTA function is very difficult, because it has a strong combinatorial flavor; in fact, it has been proven to be NP-complete by Lloyd and Witsenhausen in 1986. Part of the complexity relates to the fact that the kill probabilities p_{ij} are different. If the kill probabilities are the same, i.e., $p_{ij}=p$ for all i and j, then the optimal solution (to minimize the leakage) is easy and it requires the maximally uniform assignment of the weapons among the targets. The problem is inherently hard even in the special case when the kill probabilities depend only on the weapons but not the targets, i.e., p_{ij} is independent of i.

More realistic versions of this problem can be formulated in a similar manner. For example, each target indexed by $i=1,2,\ldots,N$ can be assigned a value of V_i reflecting the importance of that specific target to the defense. In this case, the defense may wish to minimize the expected total surviving value associated with all targets, i.e., minimize the cost function

$$C = \sum_{i=1}^{N} V_i \prod_{j=1}^{M} (1-p_{ij}x_{ij}) \tag{3}$$

again by selecting optimally the M.N allocation decision variables x_{ij}, subject to the constraints of Eq. (2).

Another, still more complicated, problem couples the WTA problem to that of preferential defense. In this framework we explicitly take into account the value of the defense assets. So let us suppose that the defense wishes to protect a total of Q assets, indexed by $q=1,2,\ldots,Q$, and that each asset has a value denoted by D_q. Each one of the defense assets can be attacked by one or more enemy targets. Let π_{qi} denote the probability that the i-th target can kill the q-th asset. Note that the π_{qi} captures such important attributes as target yield, asset hardness, targeting accuracy etc. In this case we can form a utility function which the defense wishes to maximize. This utility function takes the form

$$U = \sum_{q=1}^{Q} D_q \prod_{i=1}^{N} (1-\pi_{qi} \prod_{j=1}^{M} (1-p_{ij}x_{ij})) \tag{4}$$

The above formulation allows for optimal selective defense of the defensive assets. It may be worthwhile to leave a low-value overtargeted defense asset undefended in order to direct the defensive weapons against other targets.

<u>Description of Recent Progress</u>. This research is being carried out by two doctoral students, Mr. J. Walton and Mr. P. Hossein, under the

supervision of Prof. M. Athans. Mr. Walton joined the project in June 1986, while Mr. Hossein joined the project in January 1987. Both students are working on research which will constitute their Ph.D. thesis topics in this area.

We have studied some special shoot-look-shoot ... strategies and have proven certain somewhat counterintuitive results. Suppose that all targets have the same value and that the kill probabilities are the same. We have examined multistage versions of the shoot-look-shoot (SLS) type of strategy. In the two stage version of the problem we have shown that the optimal allocation of M weapons against 2 targets is to attack at each stage in a uniform manner with (the integer nearest to) M/4 interceptors. Thus each target is attacked initially by M/4 weapons; if both targets survive then at the second stage each is attacked by M/4 weapons; if only one survives then it obviously gets attacked with M/2 interceptors (our optimization problem formulation does not try to "save" interceptors). What appears — at least to us -- to be counterintuitive is that more than one interceptor is commited during the first stage. However, it turns out that this is the optimal thing to do. A similar uniform attack strategy is true for three or more stages. In fact we have derived a recursive formula that can be used to evaluate the benefits of multi-stage SLS strategies as compared to "blind" salvo attacks. We plan to examine these problems in a different setting, e.g., when the kill probability changes as a function of the stage that the target is shot at. Also, we are examining distributed versions of this problem.

In the context of asset defense, we wanted to study the tradeoffs between the distribution of the C2 function and the change in strategies associated with the WTA algorithms. We assumed that the defense replicates R command-and-control centers. An initial assumption is that any surviving C2 center can launch and guide all interceptors to their correct targets; in this manner, the offense should attempt to destroy all R C2 centers. In the special case of perfect kill probabilities (i.e., an unintercepted target will surely destroy a C2 center and a launched interceptor will certainly kill its target) the defense should use preferential defense and defend perfectly only one of the C2 nodes. Thus, it is suboptimal for the offense to target any C2 nodes under these assumptions. It is not clear whether the above strategy remains true when the targets and interceptors have non-unity kill probabilities, and what are the thresholds and tradeoffs. At any rate, these results indicate that one should not use perfect replication of C2 functions in order to obtain more realistic solutions.

Documentation: No formal documentation exists as yet.

4. RESEARCH PERSONNEL

Dr. Alexander H. Levis, Principal Investigator
Professor Michael Athans
Professor Amedeo Odoni

Ms. Susan A. Hall	Research Assistant (Ph.D. Candidate)
Mr. Patrick Hossein	Research Assistant (Ph.D. Candidate)
Mr. Joseph Oliveira	Research Assistant (Ph.D. Candidate)
Mr. Didier Perdu	Research Assistant (MS Candidate)
Mr. James Walton	Research Assistant (Ph.D. Candidate)

Mr. John Kyratzoglou completed is thesis and graduated. Mr. Didier Perdu completed his thesis and graduated. He will be returning to MIT/LIDS in February to continue work on this project as a visiting scientist with support provided by his employer.

5.0 INFORMATION DISSEMINATION

The following documents were issued as Laboratory Technical Reports or as Technical Papers. There were submitted to ONR, to the Basic Research Group of the JDL Panel on C^3, and to the distribution list specified in the contract. Some aspects of the work contained in these reports were supported by other related projects, such as the one from the Office of Naval Research on Distributed Tactical Decisionmaking (N00014-84-K-0519).

5.1 Theses/Technical Papers

1. C. M. Bohner, "Computer Graphics for System Effectiveness Analysis," LIDS-TH-1573, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA July 1986.

2. P.J. F. Martin, "Large Scale C^3 Systems: Experimental Design and System Improvement," LIDS-TH-1580, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA August 1986.

3. H. P. Hillion, "Performance Evaluation of Decisionmaking Organizations Using Timed Petri Nets," LIDS-TH-1590, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA September 1986.

4. S. T. Weingaertner, "A Model of Submarine Emergency Decisionmaking and Decision Aiding," LIDS-TH-1612, S. M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA September 1986.

5. P. A. Remy, "On the Generation of Organizational Architectures Using Petri Nets," LIDS-TH-1630, S.M. Thesis, Laboratory for Information and decision Systems, MIT, Cambridge, MA December 1986.

6. J. Kyratzoglou, "Computer-Aided Design for Petri Nets," LIDS-TH-1694, M.E. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA September 1987.

7. D. Perdu, "Modeling and Evaluation of Expert Systems in Decision-Making Organizations," LIDS-TH-1726, M.E. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA December 1987.

5.2 Technical Papers

1. P. Remy, A. H. Levis, and Y.-Y. Jin, "Delays in Acyclical Distributed Decisionmaking Organizations," LIDS-P-1528, Laboratory for Information and Decision Systems, MIT, January 1986, also in Proc. 10th World Congress of the International Federation of Automatic Control, Munich, FRG, July 1987: Revised version to appear in Automatica, January 1988.

2. A. H. Levis, "Modeling the Measuring Effectiveness of C^3 Systems," LIDS-P-1608, Laboratory for Information and Decision Systems, MIT, September 1986. Proc. Seventh Annual AFCEA European Symposium, Brussels, Belgium, October 1986.

3. M. Athans, "Command-and-Control Theory: A Challenge to Control Science," LIDS-P-1584, Laboratory for Information and Decision Systems, MIT, September 1986; also IEEE Transactions on Automatic Control, Vol. AC-32, No. 4, April 1987.

4. P. A. Remy and A. H. Levis, "On the Generation of Organizational Architectures Using Petri Nets," LIDS-P-1634, Laboratory for Information and Decision Systems, MIT, January 1987, also in Proc. Eighth European Workshop on Applications and Theory of Petri Nets, Zaragoza, Spain, June 24-27, 1987.

5. H. P. Hillion and A. H. Levis, "Timed Event-Graph and Performance Evaluation of Syustems," LIDS-P-1639, Laboratory for Information and Decision Systems, MIT, January 1987, also in Proc. Eighth European Workshop on Applications and Theory of Petri Nets, Zaragoza, Spain, June 24-27, 1987.

6. A. H. Levis and M. Athans, "The Quest for a C^3 Theory: Dreams and Realities," LIDS-P-1691, Laboratory for Information and Decision Systems, MIT, August 1987, in Proc. 1987 Symposium on C^2 Research, National Defense University, Fort McNair, Washington DC, December 1987.

7. H. P. Hillion and A. H. Levis, "Performance Evaluation of Decisionmaking Organizations," LIDS-P-1683, Laboratory for Information and Decision Systems, MIT, July 1987, also in Proc. 1987 Symposium on C^2 Research, National Defense University, Fort McNair, Washington DC, December 1987.

8. A.C. Louvet, J. T. Casey, and A. H. Levis, "Experimental Investigation of the Bounded Rationality Constraint," LIDS-P-1680, Laboratory for Informaion and Decision Systems, MIT, July 1987, also in Proc. 1987 Symposium on C^2 Research, National Defense University, Fort McNair, Washington DC, December 1987.

9. S. T. Weingaertner and A. H. Levis, "Evaluation of Decision Aiding in Submarine Emergency Decisionmaking," LIDS-P-1688, Laboratopry for Information and Decision Systems, MIT, August 1987, also in Proc. 1987 Symposium on C^2 Research, National Defense University, Fort McNair, Washington DC, December 1987.

10. P. J. F. Martin and A. H. Levis, "Measures of Effectiveness and C^3 Testbed Experiments," LIDS-P-1678, Laboratory for Information and Decision Systems, MIT, July 1987, also in Proc. 1987 Sympsoium on C^2 Research, National Defense University, Fort McNair, Washington DC, December 1987.

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